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FROM THE

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EXAMINATION AND SURVEY
OF
SACRAMENTO RIVER
CALIFORNIA

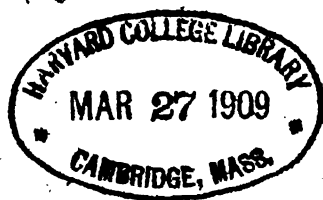
FROM ITS MOUTH TO
FEATHER RIVER



DECEMBER 9, 1908.—Referred to the Committee on Rivers and Harbors
and ordered to be printed with illustrations

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

Eng 1019 49.3



U. S. Government

SACRAMENTO RIVER. CALIFORNIA.

LETTER

FROM

THE SECRETARY OF WAR,

TRANSMITTING.

WITH A LETTER FROM THE CHIEF OF ENGINEERS, REPORTS OF
EXAMINATION AND SURVEY OF SACRAMENTO RIVER. CALI-
FORNIA, FROM ITS MOUTH TO FEATHER RIVER.

DECEMBER 9, 1908.—Referred to the Committee on Rivers and Harbors and
ordered to be printed with illustrations.

WAR DEPARTMENT,
Washington, December 7, 1908.

SIR: I have the honor to transmit herewith a letter from the Chief
of Engineers, U. S. Army, dated 4th instant, together with copies of
reports from Capt. Thomas H. Jackson, Corps of Engineers, dated
August 6, 1907, and October 10, 1908, of a preliminary examination
and survey, respectively, of Sacramento River, California, from its
mouth to Feather River, made by him in compliance with the
provisions of the river and harbor act of March 2, 1907.

Very respectfully,

LUKE E. WRIGHT,
Secretary of War.

THE SPEAKER OF THE HOUSE OF REPRESENTATIVES.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, December 4, 1908.

SIR: I have the honor to submit herewith, for transmission to
Congress, reports of August 6, 1907, and October 10, 1908, with maps,
by Capt. Thomas H. Jackson, Corps of Engineers, on preliminary
examination and survey, respectively, authorized by the river and

harbor act approved March 2, 1907, of Sacramento River, California, from its mouth to Feather River.

The present project for improving Sacramento River provides for securing a least channel depth of 7 feet up to the city of Sacramento, 4 feet to Colusa, and 3 feet to Red Bluff. The project depths of 7 feet to Sacramento, and 4 feet to the mouth of Feather River, have been obtained.

In connection with the present investigation, depths of 9, 12, and 15 feet up to Sacramento, and 6 and 9 feet up to the mouth of Feather River, have been considered, and estimates therefor are included in the reports herewith.

In concluding his report of October 10, 1908, Captain Jackson recommends an increase in project depth to 9 feet for the river below Sacramento, at an estimated first cost of \$67,000, and \$42,000 annually for maintenance, but further improvement beyond that called for by the present project above Sacramento to the mouth of the Feather River is not recommended.

I concur in the opinion of the district officer, the division engineer, and the Board of Engineers for Rivers and Harbors that an increase in depth to 9 feet below Sacramento is worthy of being undertaken by the General Government, but that further improvement above Sacramento than that called for by the existing project is not advisable at the present time.

As one of the most serious problems in connection with the Sacramento River is the control of floods, the plan of improvement presented is in harmony with any rational system of control that may be adopted.

Very respectfully,

W. L. MARSHALL,
Chief of Engineers, U. S. Army.

The SECRETARY OF WAR.

PRELIMINARY EXAMINATION OF SACRAMENTO RIVER, CALIFORNIA,
FROM ITS MOUTH TO FEATHER RIVER.

UNITED STATES ENGINEER OFFICE,
San Francisco, Cal., August 6, 1907.

SIR: I have the honor to submit the following report upon a preliminary examination of the Sacramento River, California, from its mouth to the Feather River, made in compliance with first indorsement, Office of the Chief of Engineers, U. S. Army, dated June 28, 1907, and pursuant to the requirement of the river and harbor act approved March 2, 1907:

The river and harbor act of June 3, 1896, provided for the appointment of a board of three engineers of the United States Army for the purpose of making surveys and examinations of the Sacramento and Feather rivers, and submit the most feasible plan for the improvement of said rivers and the maintenance of navigation thereon, and to have charge of the work by them recommended as appropriations are made therefor.

In its report (printed in the Annual Report of the Chief of Engineers for 1899, p. 3171) the Board submitted a project for obtaining a least channel depth of 7 feet in the Sacramento River below Sacra-

mento, by means of a system of wing dams, to be supplemented by dredging, if necessary, at an estimated cost of \$280,000; for a 4-foot depth above Sacramento to Colusa, and for a 3-foot depth above Colusa to Red Bluff, by the removal of snags and the concentration of channel widths by temporary works, at an annual expense of \$25,000. This constitutes the present project for the improvement of the Sacramento River.

The river has responded readily to treatment and little difficulty has been experienced in obtaining the depths called for in the present project in the portion of the river under consideration. Operations under this project have resulted in obtaining the least depth of 7 feet in the 64 miles of the river from its mouth up to Sacramento and 4 feet in the 91 miles from Sacramento up to Colusa.

This river empties into Suisun Bay, which has a least navigable depth of about 13 feet at mean low water.

The part of the river under consideration is naturally divided at Sacramento into two parts, so far as the commerce and width of stream and depth of water are concerned. Above Sacramento the river is from 600 to 1,000 feet in width at low stages, while below, except for the last few miles, it is from 400 to 600 feet. The lower portion carrying in addition the water from the American River, which enters at Sacramento, is consequently much deeper.

In the lower 50 miles or so the river has a sort of delta formation, with numerous sloughs, all carrying water at the higher stages and many carrying water at all stages. To reclaim the islands thus formed and the lowlands that extend along the entire river on both sides high levees have been constructed along what was probably the low-water channel, so that at present the river flows ordinarily between these levees.

With the exception of an occasional shoal at points where the river broadens, below where there has been a break in the levee during flood season, or below a large slough, there is a much greater depth of water throughout than called for under the existing project, and these shoals appear only at the low-water stage, which is a short one—about two or three months. This is due to the fact that enormous quantities of the water brought down during the spring floods escape into the large lowland basins along the upper river and its tributaries, and it takes several months for this water to drain back into the river.

The season of lowest water, however, is during the period when there is the most navigation, which makes the demand for increase in depth the more urgent and important. Many boats and barges are in commission only during this period. Again, the draft of the larger boats plying on this river is so near the limiting low-water depth that they can not be fully loaded during that portion of the year when they would ordinarily carry the greatest cargoes.

The effect of the tide is felt at low-water stages as far upstream as Sacramento, about 65 miles, but at the higher stages it does not extend very far upstream. In the lower 20 miles or so, however, the action of the tide is pronounced at even the highest flood stage.

The construction of the levees in the lower stretch of the river, and especially below Grand Island, is said to have raised the flood plane several feet at Rio Vista, a point about 16 miles from the mouth. No survey of the river below Sacramento has been made during the past

eleven years, the last survey being that of 1895-96, and no gauge records have been kept, hence it is impossible to verify these reports.

As shown by the existing project, paragraph 1 and in paragraph 4, in the consideration of the portion below the mouth of the Feather River, that portion below the American River should be considered apart from that above, for practically all of the commerce in the latter stretch comes from points that are above the Feather River, and there can be no object in improving this portion without extending the improvement to about Colusa, a point about 70 miles farther upstream, for at this time this lower stretch has better water than is found at points near Colusa.

Again, Sacramento city is a large distributing point. It is the only town of any size on the lower river, and practically all upstream commerce in the lower river terminates at that city. An increase in depth of water would undoubtedly be of great benefit to the type of boats now operating on the lower river in allowing them to carry full loads and attain greater speed at low-water stage, and, in addition, if the increase in depth were sufficient, a number of the coast-wise steam schooners carrying lumber, shingles, etc., would undoubtedly go upstream to Sacramento instead of transferring their cargoes to scows, as is done at present.

The commerce on this river is large, averaging about 425,000 tons for the past twelve years, with an estimated tonnage of 500,000 for the last fiscal year. This commerce is mostly farm produce, hay, grain, vegetables, and fruit, which has a very high value per ton. The estimated value of the commerce during the past fiscal year is \$22,500,000, from which some idea can be had of the importance of this river as a transporting agent. The greater part of this commerce, considering both quantity and value, is carried on during the late summer and the fall months, when the river is at or near the low-water stage.

About June 5, 1907, I made an examination of the river above Sacramento, and on July 16, 1907, an examination of that portion below Sacramento. At both times the river was too high for an opinion to be formed of the low-water stage conditions, but all available data have been considered and all possible information obtained from parties interested in navigation or its improvement.

But one survey has been made of this river, and owing to the known changing condition of this river it is too old to be of any assistance in the study of the river, except in connection with a new survey. The question of the improvement of this river is one that will depend almost entirely on what a survey will show of the actual existing conditions and the changes that are going on in the river bed.

It is my opinion that the portion of the river under consideration is worthy of improvement, from its mouth to Sacramento, beyond that contemplated in the present project, but to what extent it is impossible to state at present; and that a survey should be made in order that the amount, character, and cost of the improvement that will be necessary to secure further increases in depth may be ascertained and an idea obtained of the cost of maintenance of any increase in depth.

The California Débris Commission proposes to make a survey of that portion of the river above Sacramento during the next dry season, in connection with the restraining of débris.

It is therefore recommended that a survey be made of that portion of the river below Sacramento. The cost of this survey is estimated at \$7,500.

In the consideration of this problem I have consulted with the Sacramento and Feather River Board, and this board agrees in the opinion that the river is worthy of improvement beyond the present approved project, and that a survey should be made as recommended.

Very respectfully, your obedient servant,

THOS. H. JACKSON.

Captain, Corps of Engineers.

The CHIEF OF ENGINEERS, U. S. ARMY.
(Through the Division Engineer.)

[First indorsement.]

UNITED STATES ENGINEERS OFFICE, PACIFIC DIVISION.

San Francisco, Cal., August 13, 1907.

Respectfully forwarded to the Chief of Engineers, U. S. Army, recommended for approval.

The navigation interests of the Sacramento River are large, and if a deeper channel, up to 15 feet, can be secured at a reasonable cost it is in my opinion desirable. The lower reaches of the river are rapidly changing, a number of new levees have been recently constructed so that information subsequent to the survey of 1895 is necessary.

The number of side sloughs to be surveyed, the desirability of obtaining high and low water discharges at various points, and the necessity of tidal observations at various stages of the river make the estimate a very reasonable one.

Attention is invited to the recommendation of a survey of Suisun Bay, sent forward from this office, which bay is part of the channel from the Sacramento River to San Francisco.

JOHN BIDDLE.

Lieut. Col., Corps of Engineers.

Division Engineer.

[Third indorsement.]

BOARD OF ENGINEERS FOR RIVERS AND HARBORS.

Washington, D. C., February 24, 1908.

Respectfully returned to the Chief of Engineers, U. S. Army.

The improvement of the Sacramento River has been the subject of much study by a number of prominent engineers, boards, and commissions, and has involved questions of navigation and other interests intimately connected. A number of valuable reports have been published which indicate the expenditure of much time and thought. In taking up the question of the improvement of this river, one is impressed with the magnitude and variety of the problems involved, and at once recognizes the necessity of having complete and accurate data regarding the physics of the stream before it is possible to express a definite opinion upon the many problems presented. In each of the important reports heretofore published the statement is noted that estimates of cost, discharge, slope, and predictions as to

* See House Doc. No. 1110, Sixtieth Congress, second session.

the probable result of the works proposed, are approximate only, as they are based on insufficient data.

No complete and comprehensive survey, including the collection of such data as are essential for a proper study of the improvement of this stream, has ever been made, and the Board has reached the conclusion, after a preliminary examination of available data, supplemented by a personal inspection of the river by a committee of the Board and information obtained at a public hearing held at Sacramento on January 20, 1908, that the many important interests involved make it desirable that such a survey and investigation should be made. The estimate of the district officer for a survey, \$7,500, is, in the opinion of the Board, insufficient for the character of survey deemed necessary in this case. The Board believes that a complete detailed survey is fully justified by the many important interests concerned, and that whether or not it is followed immediately by favorable recommendations for a more extensive improvement of navigation than is contemplated by the existing project, it will be of inestimable value in the future in the solution of problems that are almost certain to arise, and which will be of importance to the United States.

It is recommended that such sum be allotted as may be necessary for a complete and detailed survey, including the following:

1. A careful line of precise levels.
2. The establishment of permanent bench marks.
3. A system of tertiary triangulation.
4. Sufficient topography to locate all principal physical features, such as levels, sloughs, cut-offs, creeks, and tributary streams within the flood zone.
5. The establishment of water gauges at critical points.
6. A series of discharge observations of sufficient extent to determine the flow at high, medium, and low stages.
7. Sufficient hydrography to determine existing depths, together with characteristic cross sections, the ends of which should be marked for future reference.
8. The determination of the slope at high, low, and intermediate stages.

After this survey has been made, the question of the improvement of the stream can then be taken up intelligently. It is recommended that estimates be made for channels 9, 12, and 15 feet in depth to Sacramento, and for 6 and 9 feet in depth between Sacramento and the mouth of Feather River.

The Board has under consideration the improvement of San Joaquin River also, and it has decided to recommend a survey of the same character for that stream. These rivers form a delta common to both, and they are intimately connected in many ways. They are subject to the same influences, and by connecting waterways and through the topping of levees their flood waters mingle. These streams unite at Collinsville and proceed in the same channel through Suisun Bay. It is evident, therefore, that the work involved in the surveys should be coordinated into one harmonious plan.

It is desirable that the map resulting from this survey should take in the entire flooded district, but it may not be necessary to cover the entire area with the survey, as existing maps or data, if reliable,

may be used for districts remote from the main river. The survey should extend through Suisun Bay to the vicinity of Benicia.

For the Board:

D. W. LOCKWOOD,
*Colonel, Corps of Engineers,
Senior Member of the Board.*

[Fourth Indorsement.]

WAR DEPARTMENT.
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, February 29, 1908.

Respectfully submitted to the Secretary of War.

This is a report on preliminary examination of Sacramento River, from its mouth to Feather River, California, authorized by the river and harbor act of March 2, 1907.

Inviting attention to the report of the Board of Engineers for Rivers and Harbors in the preceding indorsement, I recommend that a survey of the locality, as proposed, be authorized.

A. MACKENZIE,
Brig. Gen., Chief of Engineers, U. S. Army.

[Fifth Indorsement.]

WAR DEPARTMENT,
March 2, 1908.

Approved as recommended by the Chief of Engineers.

ROBERT SHAW OLIVER,
Acting Secretary of War.

SURVEY OF SACRAMENTO RIVER, CALIFORNIA, FROM ITS MOUTH
TO FEATHER RIVER.

WAR DEPARTMENT,
UNITED STATES ENGINEER OFFICE,
San Francisco, Cal., October 10, 1908.

SIR: I have the honor to submit the following report on the survey of the Sacramento River from its mouth to the Feather River, as authorized by letter dated March 5, 1908.

This survey was carried on in connection with the surveys of the San Joaquin River and Suisun Bay made by Lieut. Col. John Biddle, Corps of Engineers. Mr. H. H. Wadsworth, assistant engineer, of this office, was in the immediate charge of all the surveys. A copy of his report is attached, and attention is invited to it for details of the work.

The instructions covering this survey will be found in the report of the Board of Engineers for Rivers and Harbors on the preliminary survey, and they have been observed as closely as possible in making this survey.

Much of the data to be obtained in order to comply with these instructions can be obtained only by observations extending over several years.

The United States Geological Survey has gauging stations on all the principal tributaries of this river, and their observations extending over about five years are available in the published documents of that bureau, therefore it was not considered necessary to make any extended low-water discharge observations.

The reasons for taking any observations were the unusual low-water discharge of the river this season, being probably less than for any year covered by the observations of the United States Geological Survey, and the fact that their observations this season were not available; again, it was desirable to know what portion of the flow passes through the various channels into which the lower river divides below Sacramento.

Since the observations of the United States Geological Survey are available, it did not seem necessary to make any discharge observations of the medium flow this season, and it is not proposed to make any flood discharge observations.

In 1907 the California Débris Commission established gauges at critical points along the river below Sacramento, and observations have been carried on now for over a year. Those gauges will be maintained for some time yet by that commission, and from the records of that office the slopes at high, low, and intermediate stages can be obtained. Those records were used in the determination of the adopted grade line.

The adopted grade line for this survey is at mean low water at Collinsville and at elevation 8.5 at Sacramento. The intermediate points were determined by observation at the proper stage of the tide. The resulting grade line is in general lower than that of the previous surveys of the river, on account of the extreme low stage of the river this season.

The instructions also called for a map showing the entire flooded district of the Sacramento and San Joaquin rivers. To comply with this a map has been made to the scale of 1:60,000. The data for this map have been obtained from the existing maps of the United States Geological Survey, those of the California Débris Commission, from local county railway location maps, and from the map of this survey.

From the United States Geological Survey there was obtained a list of all their precise level bench marks and their triangulation stations lying within the limits of this survey, and those benches and stations were used as far as possible in making this survey.

Much information was also obtained from the California Débris Commission, and their survey of the portion of the river above Sacramento made in 1907 has been included in the map of this survey. This reduced the field work of this survey to that portion of the river below Sacramento, with soundings in the river above Sacramento to the mouth of the American River.

The field work was begun about May 1 and completed about September 30. The data obtained has been plotted on 26 sheets to a scale of 1:4,800.

A description of the river and its commerce was given in the report on the preliminary examination, dated August 6, 1907, to which I desire to refer in connection with this report.

From an examination of the records of the United States Geological Survey covering the period 1903-1907, inclusive, it is estimated that the average low-water flow of the Sacramento River below the mouth of the American is as follows: August, 9,230 cubic feet per second; September, 7,820 cubic feet per second; October, 9,580 cubic feet per second; with a minimum discharge of 5,900 cubic feet per second for September, 1905.

The discharge for August, 1908, is estimated by the district engineer of the United States Geological Survey as 6,740 cubic feet per second. It is estimated that the discharge for September, 1908, was considerably less than that of August, and that it was less than the discharge of September, 1905. The observations of this office during the period August 3-17 gave a discharge of about 7,400 cubic feet per second, of which about 27 per cent flowed through Steamboat Slough and about 24 per cent through Georgiana Slough.

A comparison of this survey with that of the survey of 1895-96 shows that the river is improving as a navigable channel and that it is recovering from the effects of unrestricted hydraulic mining. It is estimated that the river bed for a distance of 14 miles immediately below Sacramento has lowered 2 feet in the past twelve years. The American and the Feather rivers, however, are still full of debris, and the effect of the sand deposits in the American River on the Sacramento River are noticeable for a considerable distance below the mouth of that river, and the fact that these two rivers contain probably more than 500,000,000 cubic yards of fine material, all of which must eventually pass down the Sacramento River to Suisun Bay, must be borne in mind in any consideration of the improvement of this river.

It is estimated that the maximum flood discharge of the river during the flood of March, 1907, if it had been confined to the river channel, would have exceeded 500,000 cubic feet per second. It is seen, therefore, that the minimum low-water discharge is about 1 per cent of the maximum flood discharge.

Owing to the extreme low water this season, it is probable that the conditions regarding navigation are worse than they will be for many years to come, and the low-water plane assumed is undoubtedly considerably below the average low-water plane. It is estimated that in the vicinity of Sacramento it is about 2 feet below the low-water plane of 1907.

The discharge of this river at flood stages is so great that the quantity of material brought into it by its debris-bearing tributaries will probably destroy each season any channel secured during the previous low water, hence its permanent improvement involves the removing of the present deposits in its tributaries, the Feather and American, as well as the present deposit in its bed.

The original soundings for this survey in the vicinity of Sacramento were made in May when the river was at about a 16-foot stage. About the latter part of July it became evident that the river bed had changed sufficiently to justify re-sounding in the 13 miles immediately below Sacramento. This was done in September when the river was at its lowest stage (about a 5½-foot stage). A comparison of these soundings shows that the deposit in the channel in the distance mentioned was at least 3,000,000 cubic yards. This gives

some idea of the quantity of material carried by the river at the lower stages.

The improvement of this river is further complicated by the great flood discharge, for the estimated flood-carrying capacity of the river is only about 60,000 cubic feet per second, or about 12 per cent of its estimated maximum flood discharge. (Flood of March, 1907.)

The great problem of the Sacramento River is its flood control, and the data obtained by this survey will be of service in the solution of that problem and the execution of the resulting project. Improvement for navigation is of secondary importance, and no project for such improvement should be considered that will decrease the present flood capacity of the river or will interfere in the execution of a flood-control project. Any means of river improvement that involves the use of jetties, etc., and reduces the flood capacity should be avoided, if possible.

The only available method, therefore, of obtaining increased depths is by means of dredging, and that method is recommended in the projects and estimates of this report. Any work done under the recommended project will in no way interfere with the execution of flood-control projects, and it may be made to assist materially in their completion.

The river from Sacramento to the Feather River has a present low-water navigable depth of 4 feet. The survey shows that there is a low-water depth of 6 feet throughout this portion of the river, except for about 1½ miles, practically all of which is below the mouth of the American River, and that there is a low-water depth of 9 feet for about 16 miles of the 21 miles.

The river below Sacramento has a navigable low-water depth of 7 feet, which has been maintained under the present project. This survey shows that, considering a 200-foot channel width, there is less than 9 feet for a distance of about 3 miles; that there is less than 12 feet for a distance of about 9 miles; and that there is less than 15 feet for a distance of about 15 miles. Considering a narrower channel, these distances are considerably reduced.

An examination of this survey shows the great superiority of the Old River over Steamboat Slough as a navigable channel, its one disadvantage being its greater length. Moreover, practically all of the important landings are on Old River. Therefore, in preparing the estimates on the several projects, the improvement of Old River as the main navigable channel is considered.

As stated before, any improvement by dredging will be of a temporary benefit and confined to a single low-water season. The river, however, is gradually getting rid of its hydraulic mining deposits and the navigable depths are improving. Hence, as the bed of the river lowers, the amount of dredging to be done annually to maintain increased depths should decrease.

There are two methods of dredging and disposing of the dredged material:

First. Use of hydraulic dredges which will deposit the dredged material on the banks in storage.

Second. Use of clam-shell dredge, which will deposit the dredged material on the present levees or in the river bed outside of the deepened channel.

For the 6-foot channel above Sacramento, and the 9-foot channel below, it is estimated that one-half of the excavated material can be disposed of by each of these methods. For the greater channel depths, however, the quantity of material is so great that the estimates are based on the placing of all the material on the bank. Any considerable quantity of material in the river bed might cause the river to overflow the levees above in case of a sudden rise, or endanger the levees opposite the point where it is stored, until it is washed downstream. All emergency work, however, will probably be done by the second method.

There is no objection to the excavated material going downstream during high water and filling the dredged channel below, for, as indicated above, those channels will undoubtedly be filled anyway every flood season.

The question of the storage of the dredged material on the banks is a serious one, especially for the projects involving the dredging of large amounts, as is the case with the 12 and 15 foot projects below Sacramento, and the 9-foot project above.

The land along the river is lower than the surface of the river, except at its low-water stage, and the ground adjacent to the river slopes away from it, making it difficult to drain the water from the dredging operations back into the river, and at most places that must be done.

The construction of the levees on the land side to hold the dredged material will be expensive, unless they inclose large tracts and are raised on the deposited dredged material from time to time. For this reason sufficient land should be secured to provide for storage for a number of years and the entire area utilized from the first. This will admit of the securing of large tracts of land at the most suitable sites. It will also make it possible to secure the land at a more reasonable cost, as much of it is at present not highly improved.

It is thought that in the case of the 9-foot project above Sacramento and the 12 and 15 foot projects below, this storage should be sufficient for at least five years, and for the 6-foot project above Sacramento and the 9-foot project below it should be sufficient for at least ten years, based on a final average depth of deposit of 10 feet.

Borings in the river and the observations of various dredging operations show that no hard material will be found within the limits of the proposed dredging.

Estimates on the various projects are based on:

First. Channel width of 200 feet at bottom.

Second. Slopes of 1 on 4.

Third. Dredging to 2 feet below the projected depth in the vicinity of Sacramento and to 1 foot below the projected depth farther downstream.

Fourth. Six cents per cubic yard where the dredging is done with clam-shell dredges, 12½ cents per cubic yard where the dredging is done with hydraulic dredges and the quantity is large, and 15 cents where the dredging is done with hydraulic dredges and the quantity is small.

Six-foot low-water channel above Sacramento.

275,000 cubic yards, at 6 cents-----	\$16, 500
275,000 cubic yards, at 15 cents-----	41, 250
165 acres, at \$200-----	33, 000
Total -----	90, 750
Annual maintenance -----	57, 750

Nine-foot low-water channel above Sacramento.

1,660,000 cubic yards, at 12½ cents-----	\$207, 500
520 acres, at \$200-----	104, 000
Total -----	311, 500
Annual maintenance -----	207, 500

Nine-foot low-water channel below Sacramento.

200,000 cubic yards, at 6 cents-----	\$12, 000
200,000 cubic yards, at 15 cents-----	30, 000
125 acres, at \$200-----	25, 000
Total -----	67, 000
Annual maintenance -----	42, 000

Twelve-foot low-water channel below Sacramento.

1,760,000 cubic yards, at 12½ cents-----	\$220, 000
550 acres, at \$200-----	110, 000
Total -----	330, 000
Annual maintenance -----	160, 000

Fifteen-foot low-water channel below Sacramento.

4,300,000 cubic yards, at 12½ cents-----	\$537, 500
1,350 acres, at \$200-----	270, 000
Total -----	807, 500
Annual maintenance -----	425, 000

At present there is a 4-foot low-water channel from Sacramento city to the mouth of the Feather River, which is as great a depth as is at present available to Colusa. Colusa is the point at which transshipment is made from points along the upper river, and the controlling depths in the stretch between Colusa and Sacramento are found immediately below Colusa. As stated in my preliminary report, there is no object in considering increased depths between the mouth of the Feather River and Sacramento, except in connection with increased depths between the former point and Colusa.

Furthermore, it is considered that the present available low-water depth is sufficient for the present, or for any anticipated commerce above Sacramento city.

In view of the above facts, the river is not considered worthy of improvement between Sacramento and the mouth of the Feather River beyond its present capacity, and no further improvement is recommended.

The present project calls for a navigable low-water channel below Sacramento of 7 feet, and during the past three years this has

been maintained without difficulty. The only dredging that has been done was this season when a cut was made through a bar about $3\frac{1}{4}$ miles below Sacramento, at a cost of about \$3,000. It is considered, however, that a depth of 7 feet at low water is not sufficient for the present commerce.

The larger boats of the type now navigating the lower Sacramento River at times draw as much as $6\frac{1}{4}$ feet, and it is probable that they would occasionally load still heavier than at present if there was a greater depth available. The fruit season was at its height this year at about the low-water stage of the river, and at that time the steamers were carrying their greatest cargoes. It is thought that the depth at low water should be increased to 9 feet in order to admit of heavier loading, if desired, and to admit of greater speed and safety.

An increase in the navigable low-water channel depth to 12 feet would not produce any material increase in the present commerce in the Sacramento River, for there is no type of vessels on this coast adapted to that draft. The only benefits derived would be greater facilities for safe navigation to the present vessels, due to the excess depths, which benefits are not commensurate with the estimated cost and maintenance.

An increase in the navigable low-water channel depth to 15 feet would permit many of the steam schooners now engaged in the coast-wise trade to reach Sacramento, but the increase in commerce would not be great, and it is thought it would not be commensurate with the original cost of about \$800,000 and the excessive maintenance cost of about \$425,000.

It is therefore recommended that the project for a 9-foot low-water channel from Sacramento to the mouth of the river be adopted, at a cost of \$67,000 and an annual maintenance of about \$42,000.

Very respectfully, your obedient servant,

THOS. H. JACKSON,
Captain, Corps of Engineers.

The CHIEF OF ENGINEERS, U. S. ARMY.
(Through the Division Engineer.)

[First Indorsement.]

SAN FRANCISCO, CAL., *October 13, 1908.*

Respectfully forwarded to the Chief of Engineers, U. S. Army, approved.

JOHN BIDDLE,
Lieut. Col., Corps of Engineers,
Division Engineer, Pacific Division.

[Third Indorsement.]

BOARD OF ENGINEERS FOR RIVERS AND HARBORS,
Washington, D. C., November 9, 1908.

Respectfully returned to the Chief of Engineers, U. S. Army.

The within is a report on the comprehensive survey of the Sacramento River from its mouth to Feather River, which was made as a result of favorable recommendations on a preliminary examination called for by the act of March 2, 1907. At the time of the Board's investigation, which involved a public hearing and an inspection of the river, it was impressed with the magnitude and importance of the interests concerned.

The city of Sacramento is a prosperous distributing point, and its commerce both by rail and water is large. The lands adjacent to the Sacramento are extremely fertile and many of them are in a high state of cultivation under the system known as intensive farming. The lands are naturally low, and those in use are protected by large levees, many miles of which have been built by property owners. The amount of produce grown in the immediate vicinity of the river is large in tonnage and is of great value. The river being narrow and inclosed between levees, boats are able to land practically at any point, thus affording direct communication by water. The total tonnage of the river is now about 500,000 tons, valued at over \$22,000,000. There are still available for reclamation large tracts of low lands which will no doubt be gradually taken up and the traffic correspondingly increased.

Local interests have expressed a desire for an improvement which will provide for a depth of 15 feet to Sacramento city, and 9 feet to the mouth of the Feather River. In order that the merits of the case might be fully considered, estimates were made for channels 6 and 9 feet in depth between Sacramento and the Feather River, and for 9, 12, and 15 feet in depth below Sacramento. These estimates are summarized as follows:

Between Sacramento and Feather River.

6-foot depth	\$90, 750
Annual maintenance	57, 750
9-foot depth	311, 500
Annual maintenance	207, 500

Below Sacramento.

9-foot depth	\$67, 000
Annual maintenance	42, 000
12-foot depth	330, 000
Annual maintenance	160, 000
15-foot depth	807, 500
Annual maintenance	425, 000

An examination of these estimates shows the great cost of maintenance. In fact, to make permanent any increase in depth in this river involves a work of continuous maintenance, experience indicating that any deepening of the channel will be largely obliterated during the next high-water season. The district officer states that a depth of 12 feet to Sacramento would be of little more value than a depth of 9 feet, as practically the same character of boats would use it, and that while a depth of 15 feet would induce some coastwise traffic, the amount of this commerce would not be sufficient to justify the great cost of such an improvement. In this view the Board concurs, believing it to be impracticable at any reasonable cost to make a seaport of Sacramento city.

The district officer recommends a depth of 9 feet below Sacramento as being the most desirable, having in view the necessities of commerce and the cost of the work involved. Such a channel would afford facilities for large river steamers, tugs, and barges, and if its full dimensions are maintained it will provide for practically an unlimited commerce. While the cost of annual maintenance is large and equals the cost of original excavation, the Board believes that navigation and commercial interests in this locality are sufficient to

warrant the expenditure involved, and it recommends the adoption of a project below Sacramento city for a channel 9 feet in depth and 200 feet in width, at a first cost of \$67,000, including the necessary purchase of land, and an annual charge for maintenance thereafter of \$42,000.

One of the most vital problems that confront the people of this section of the country is the question of flood control. The plan of improvement recommended herein for the benefit of navigation involves dredging only and will not conflict with any project that may be adopted in the interests of the more important question. The survey and its resulting maps and data should be of great value in the solution of the flood problems.

With reference to the section of river between Sacramento city and Feather River, the district officer states that it now has a depth of 4 feet, which is the depth provided for by the existing project between Sacramento city and Colusa, and that the controlling depth is a short distance below Colusa. There appears to be no particular advantage in having a greater depth below the Feather River than between that point and Colusa, as the same boats are used over the whole distance and the character of the commerce is the same. In view of these facts, the Board concurs with the district officer and the division engineer in the opinion that Sacramento River between the mouth of Feather River and Sacramento city is not worthy at this time of improvement to a greater extent than is authorized by the existing project.

For the Board:

D. W. LOCKWOOD,
*Colonel, Corps of Engineers,
Senior Member of the Board.*

REPORT OF ASSISTANT ENGINEER H. H. WADSWORTH.

WAR DEPARTMENT,
UNITED STATES ENGINEER OFFICE,
San Francisco, Cal., October 10, 1908.

CAPTAIN: I have the honor to submit the following report on the survey of and estimates on projects for improving navigation on the Sacramento River from the mouth of the Feather River to Collinsville, made under your direction and in accordance with the recommendations (February 24, 1908) of the Board of Engineers for Rivers and Harbors.

SURVEY.

Authority to make the survey was received on March 12, coupled with instructions to make a more comprehensive survey than the preliminary estimate of cost contemplated. A further allotment of funds was asked for, and notice that this additional allotment had been made was received on April 12, 1908. In the meantime the necessary equipment was secured and parties organized. All parties were in the field before the 1st of May. This season has been exceptionally favorable for the prosecution of the work, both on account of the absence of high water in the rivers early in the season and by reason of extensive shutting down of many engineering enterprises, which made it possible to secure surveyors for this temporary employment.

As the survey of the San Joaquin River was carried on under direction of Colonel Biddle contemporaneously with that of the Sacramento River, and as the two river systems are intimately connected in many ways, and as a single map of the whole area from the mouth of the Feather on the north to the latitude of Stockton and Antioch on the south, and from the longitude of Stockton to that of Collinsville is desired, the whole work was treated as a single

survey and the several parties distributed and moved about in such a way as to cover all the required ground within the time limit.

For the purpose of this survey this whole area was treated as a plane surface. Of all survey stations, both triangulation and traverse, the rectangular coordinates were computed, the axes of which were the meridians of longitude $121^{\circ} 34'$, and the arc of a great circle at right angles to that meridian at latitude $38^{\circ} 40'$.

The azimuths of all lines of the survey are referred to this meridian, so that the fore and back azimuths of any line differ by 180° even. The difference between the azimuth referred to this meridian and the true azimuth at any point within the limits of the survey is $0^{\circ} 00' 07.8''$ for each 1,000 feet that the point is east or west of this reference meridian, which is the zero line of east and west coordinates. This rate of convergence of meridians was applied whenever azimuths for traverse work, in advance of the triangulation, were determined from astronomical observations. The resulting error for extreme east or west points of the survey is well within the limits of accuracy of the instruments used.

The triangulation and the precise-level work of the United States Geological Survey were used for the control of this survey, so far as they were available, and for the general small scale map (5,000 feet to 1 inch) of the whole area the topographical sheets of the Geological Survey were used for filling in topography away from the immediate proximity of the river, so far as these were obtainable.

For areas not covered by sheets of the Geological Survey, recently published county maps and railway location maps are used for filling in.

The datum plane of levels for this survey is the same as that used on the surveys made by the California Débris Commission of the American, Bear, Feather, and Yuba rivers. It is 3.60 feet below mean sea level as determined from B. M. of the United States Geological Survey at Sacramento. The elevation of the Sacramento B. M. had been determined by a United States Geological Survey precise-level line from a Coast and Geodetic Survey B. M. at Army Point, Benicia, the elevation of which, as accepted by the United States Geological Survey, is 0.15 foot greater than its elevation above mean half tide level as determined by observations of the Coast and Geodetic Survey. The datum plane for survey of the state engineering department and of the survey of Sacramento River made by United States engineers in 1895 and 1896, as determined from their recorded height of the zero of the gauge of United States Weather Bureau of Sacramento is 0.73 foot below the datum of this survey. A check made on B. M.'s of the United States Geological Survey at Antioch, and through their levels, on the original B. M. of the state engineering department at New York Landing shows that the datum plane of that survey at that place is only 0.12 foot below the datum plane of this survey.

A precise level line from Sacramento to Collinsville, partly by the United States Geological Survey and partly by a party on this survey, together with a series of tidal observations at Collinsville, extending over a year, gives the elevations of several tidal planes at the latter place as follows. The corresponding elevations at Army Point, Benicia, as determined by the Coast and Geodetic Survey, are also given. These elevations are referred to the datum plane of this survey.

	Collinsville.	Benicia.
Mean sea level.....	3.60	3.60
Half-tide level.....	3.85	3.75
Mean lower low water.....	.91	.20
Mean higher high water.....	6.72	6.67
Mean of three lowest tides.....	.00	
Lowest tide observed.....	.12	-1.20

Triangulation.—The triangulation system of the Geological Survey extended from Sacramento to Collinsville, but the stations were far apart, many of them were not occupiable, and in several cases they were not visible from the traverse lines. Several additional triangulation stations were established at points where the detail parties could readily tie on to them and get checks on their positions and azimuths.

For a distance of about 30 miles below Sacramento the country is very difficult for triangulation on account of the growth of timber that fringes the

river. Whenever practicable the three angles of triangles were read, but in most cases two only were observed. Each observed angle was measured by turning it off on the circle (cumulative) at least six times and dividing the total reading by the number of observations. An ordinary engineer's transit was used for this work.

Monuments consisting of 3-inch galvanized-iron pipes with brass caps, set in concrete, were set to mark the stations, or when these were on buildings, water towers, or windmills the monuments were placed near by and tied to the station.

Precise leveling.—The preliminary values for elevations of B. M.'s on an accomplished precise level line of the Geological Survey extending from Sacramento to Rio Vista were obtained from that survey. This line was extended down the river to Collinsville, as noted above. For this work a C. L. Berger precise-leveling instrument was used and excellent results were obtained.

All parts of the line were run at least twice (forward and back). Whenever the relative elevation of two successive B. M.'s as obtained from the second running of the line differed by more than $0.02\sqrt{D}$ feet, where D is the distance in miles between the B. M.'s, this part of the line was run a third time. A third running was seldom necessary. The monuments, consisting of brass-tipped pieces of pipe set in concrete, described above under the heading of "Triangulation," are marked "U. S. E. D. B. M. No.—." The elevation of these, when located along the precise-level line, were determined by the precise-level party.

Topography and hydrography.—The detail topographic and hydrographic work was done by two parties. Traverse lines were run on each side of the river, and on each side of Steamboat Slough. Cross sections were generally run at intervals of 1 mile.

In territory which had been mapped by the Geological Survey, these cross-section lines were run to a distance of about 1,000 feet from the river. At other places they were run an average distance of about 1 mile. The traverse lines on opposite sides of the river were connected at frequent intervals and closures made. They were also tied to and checked by the triangulation survey.

Levels were run over all traverse and cross section lines. Checks were made on all benches (within reach) of the Geological Survey and of the precise level lines. The elevations of existing water gauges were determined and many gauges were set for use in connection with soundings.

Such topographic details as levees, sloughs, fences, and buildings were located largely by stadia.

Soundings were taken with a pole when the depths did not exceed about 12 feet. For greater depth a lead and tagged line was used. Soundings, except in the lower, deep portion of the river, were generally spaced 30 to 40 feet apart on lines 200 feet apart. They were reduced to an assumed low-water surface grade line and platted on the field sheets. Before being traced an actual low-water surface grade line was determined by numerous gauge observations and soundings were reduced to this grade line.

This adopted grade line is at the mean lower low water (elevation 0.90) at Collinsville and at elevation 8.5 at the foot of L street, Sacramento. (This corresponds to a height of 5.4 on the Weather Bureau gauge at that point.) Since this water-surface grade line was adopted the water has fluctuated but little from this gauge height at Sacramento, having fallen on one or two days as low as 5.2 and risen as high as 5.6. Unless there is an unexpected continuance of hot, dry weather, it is not thought there will be much further drop of the river height. It has not been so low before since 1879.

For determining intermediate points on the water-surface reference grade line a date was selected when the predicted height of the lower low water was at the mean lower low water, and, in fact, when the tide gauge at Collinsville registered that stage of the tide.

An observer was stationed at each of the numerous permanent and temporary tide gauges which had been established and stage of water at low tide was taken.

The resulting grade line is lower at Sacramento than that used on previous surveys (on account of this year's very low stage of the river). It is higher at Collinsville and Rio Vista and some distance farther upstream, because it does not represent an extreme low stage of the tide, but corresponds with the mean lower low water, which is used as reference plane for soundings on charts of the Coast Survey, and is the plane to which the tide-table predictions refer.

On account of extensive deposits which formed in the river between Sacramento and Freeport after the survey of this portion had been made, the river was re-sounded at the low stage between these points.

A comparison made by plating the two sets of soundings extending over the 13½ miles of river below Sacramento show that between May and September, while the river at Sacramento fell from a stage of 16 feet to a stage of 5½ feet on the Sacramento gauge, a fill of over 3,000,000 cubic yards occurred.

Comparisons with older surveys show that the general present tendency of the river at this place is to lower its bed so that this shoaling must be due to a temporary arrest of the movement of the enormous quantity of material being carried down from the mouth of the American River, and it will doubtless be moved on again during the next flood season.

The survey of the Sacramento River from the mouth of the Feather to the mouth of the American, made by the California Débris Commission, is incorporated with this.

Up to this date the field mapping of the survey has not been quite completed, and considerable work remains to be done to complete the tracings. Soundings in all parts of the river on which any deepening will be required to procure a 15-foot channel to Sacramento have been charted and use made of them in preparing the estimates of quantitles for the several specified projects given below.

River discharge measurements.—Current meter observations were made at a station located a short distance above Courtland, between which point and the mouth of the American River there are neither tributaries nor outlet sloughs; also at two stations at Walnut Grove, one on the main river and one on Georgiana Slough. At each of these stations there is a considerable tide, and although no upstream current was observed, there was between tides a slack-water period of about forty minutes. This considerably complicated the discharge measurements and necessitated observations extending over several complete tidal cycles. These observations were all taken between August 3 and 17, when the stage of the river at Sacramento ranged from elevation 9.1 to 9.4 (6.0 to 6.3 on the gauge). The several sets of observations agreed very closely. The mean results were: At Courtland, mean discharge, 7,377 cubic feet per second; at Walnut Grove, mean discharge, Old River, 3,605 cubic feet per second; at Walnut Grove (Georgiana Slough), mean discharge, 1,970 cubic feet per second. This would leave for the flow of Steamboat and Sutter sloughs (not measured), 1,802 cubic feet per second.

While the above is not quite the minimum discharge for this season, it is probably less than the minimum discharge for the average season.

There has been no opportunity to obtain a maximum discharge measurement this year. The flood of March, 1907, was much greater than any previously recorded flood. The measurements of flow made by the United States Geological Survey on the upper Sacramento and many of its tributaries indicate a total discharge of 554,700 cubic feet per second. This estimate is from unofficial figures published in a paper in "Proceedings American Society of Civil Engineers." A large part of this passed through Yolo Basin and Cache Slough, and there were many breaks in the levees through which the water escaped from the river itself.

The cross section of the river at the Courtland current meter station, up to the high-water mark of March, 1907, or practically to the present top of the levee on the west side, measures 18,050 square feet. The levee on the east side has recently been raised. Assuming a hydraulic grade at this point parallel with the mean surface slope of the river at a low stage, which differs but little from that of the river surface during the March flood as shown by high-water marks in this vicinity, the velocity through this section would not exceed 3 feet per second; or the capacity of the present channel at this point, even to this dangerously high point, is approximately 54,000 cubic feet per second. The combined bank-full capacity of Sutter, Steamboat, and Georgiana sloughs and the main river below Walnut Grove may be sufficient to carry this discharge if the water were not backed up by a much greater discharge into the lower river through Cache Slough and held there by chokes farther downstream, as was the case during the March, 1907, flood. This problem requires much further study.

Tests of formation.—Observations of dredging operations that have been in progress at various points along the river, and of the character of material forming the levees, indicated that in deepening the channel no material was likely to be encountered that could not readily be handled by either suction or bucket dredges. For further information as to the character of the material forming the river bottom a series of tests with a water jet was made. A 2½-

inch pipe with a 1-inch nozzle was used, water being supplied by a large steam pump. A penetration to a depth below that required for either of the projects for improvement for which estimates are called for was easily obtained in all cases.

These test jettings extended from the mouth of the Feather to Walnut Grove.

All the field work of the survey, except about two weeks' work on the field maps, had been finished on September 28.

The tracings of all the sheets (of which there will be 26) will probably not be finished before November 10, and the map of the whole region, on a scale of 5,000 feet to 1 inch, will probably not be completed before December 10.

ESTIMATES OF COST OF PROJECTS FOR IMPROVEMENT OF NAVIGATION.

The following statements of estimated costs of the several projects called for by the Board of Engineers is based on prices of 6 cents per cubic yard for dredging, and casting material either into the river alongside the channel or onto the bank; 15 cents per cubic yard for dredging, towing, and pumping onto storage ground, for the 6-foot project above Sacramento and for the 9-foot project below Sacramento; 12½ cents per cubic yard for the above item on the 12-foot and 15-foot projects below and for the 9-foot project above Sacramento; \$200 per acre for land required for the storing of dredged material.

The annual maintenance cost is estimated at the same figure as the first dredging in the case of 6-foot and 9-foot projects, as it seems certain that the annual movement of material down the river will so nearly obliterate dredged channels that redredging to approximately the same extent as original work will be necessary.

In the case of the 12-foot and 15-foot projects, redredging of only a portion of the channel below Walnut Grove is provided for.

Estimates of dredging are all based on a channel width of 200 feet; and of land required on storage to a depth of 10 feet. For the larger projects, where land in large tracts would be required, storage to a greater depth could be provided for, with a consequent extension of the time of the availability of the storage ground.

Estimates of cost of projects for improving navigation on Sacramento River.

BETWEEN MOUTH OF FEATHER RIVER AND SACRAMENTO.

Project.	Dredging.			Land required.			Total first cost.	Annual maintenance cost.
	Disposition.	Cubic yards.	Cost.	Years storage.	Acres.	Cost.		
6-foot	Cast.....	275,000	\$16,500	10	165			
	Stored.....	275,000	41,250			\$33,000		
			57,750			33,000	\$90,750	\$57,750
9-foot	do.....	1,660,000	207,500	5	520	104,000	311,500	207,500

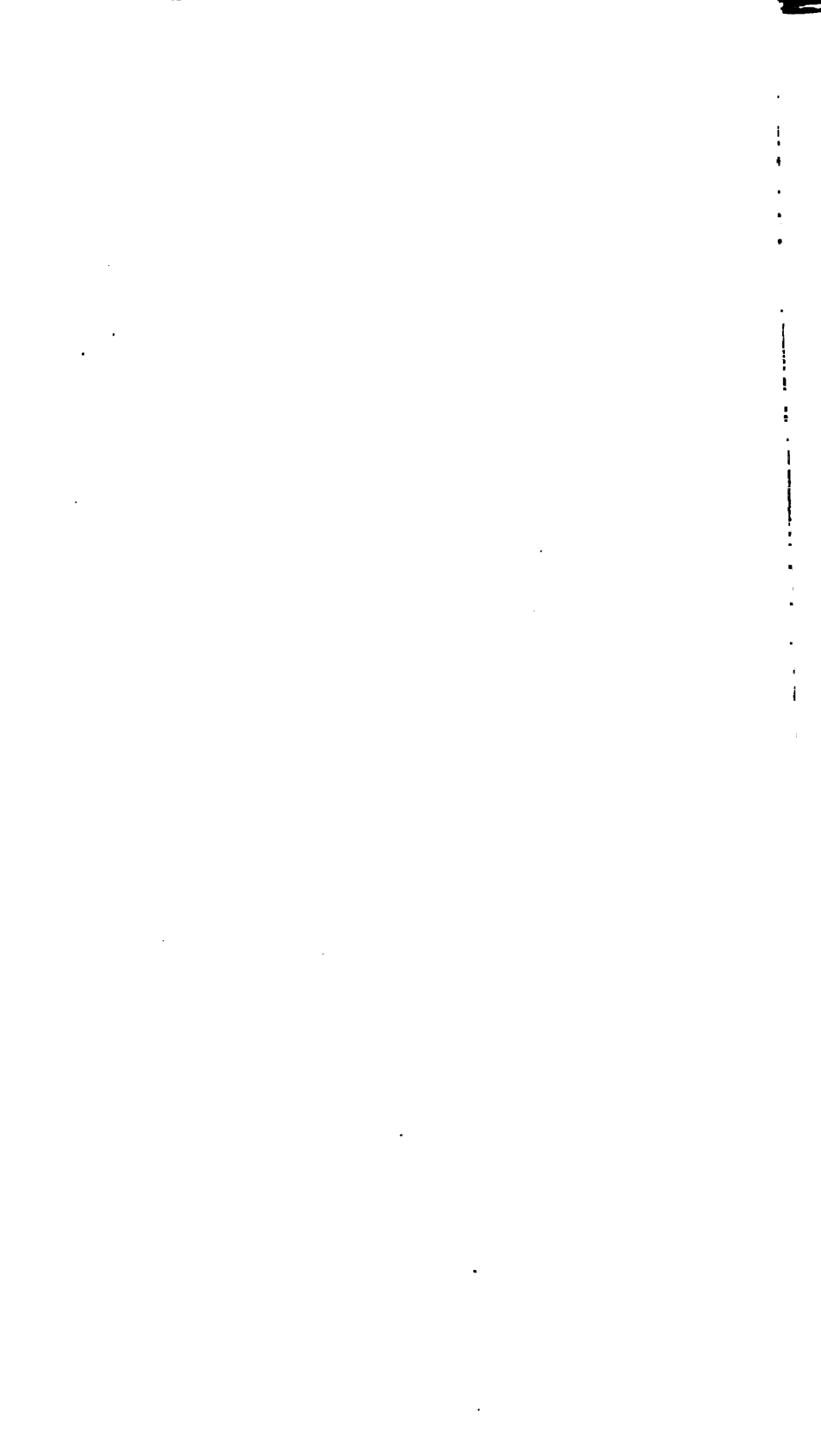
BETWEEN SACRAMENTO AND COLLINSVILLE.

9-foot	Cast.....	200,000	\$12,000	10	125			
	Stored.....	200,000	30,000			\$25,000		
			42,000			25,000	\$67,000	\$42,000
12-foot	do.....	1,760,000	220,000	5	550	110,000	330,000	160,000
15-foot	do.....	4,300,000	537,500	5	1,350	270,000	807,500	425,000

Respectfully submitted.

H. H. WADSWORTH,
Assistant Engineer.

Capt. THOS. H. JACKSON,
Corps of Engineers.



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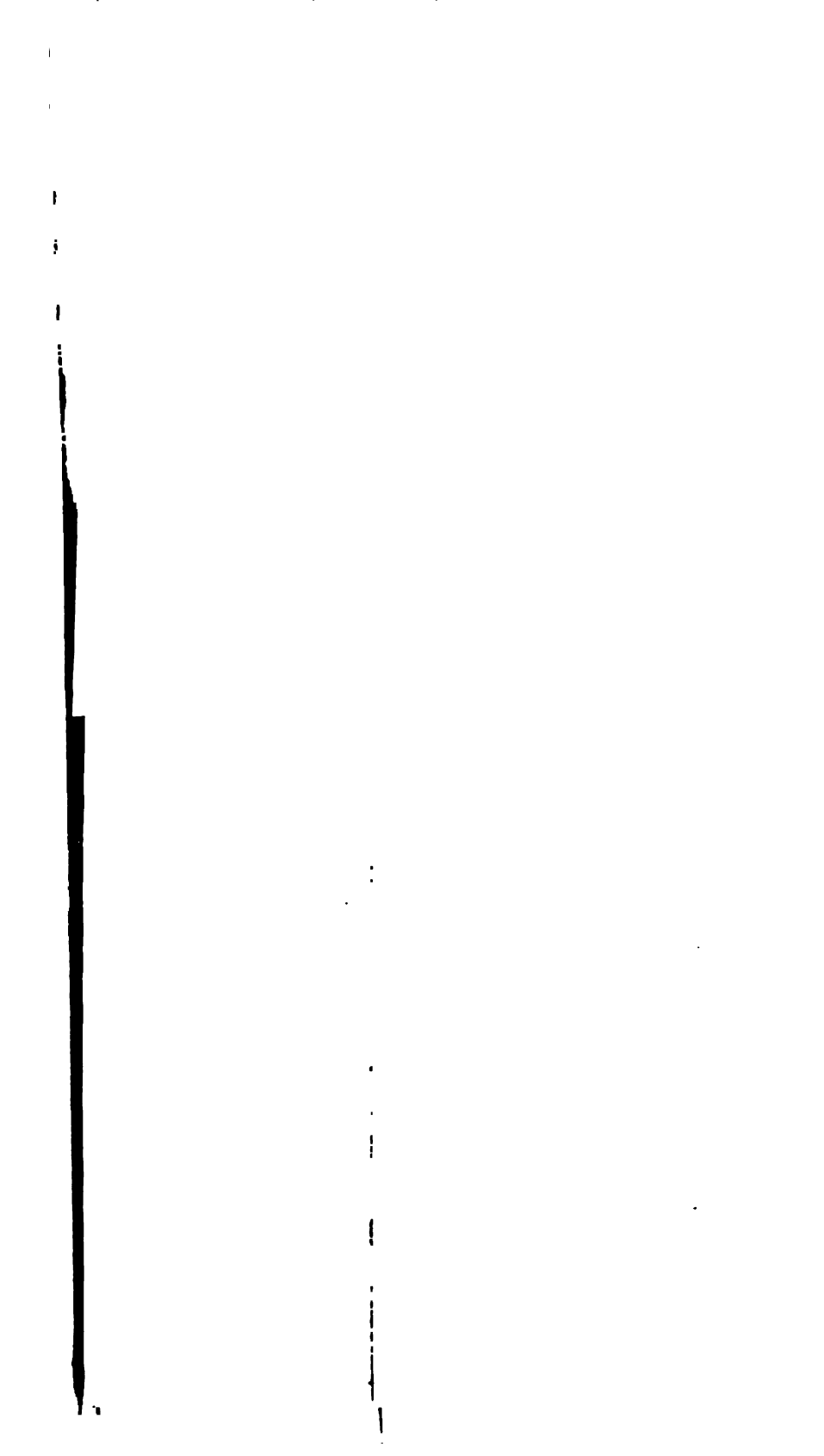
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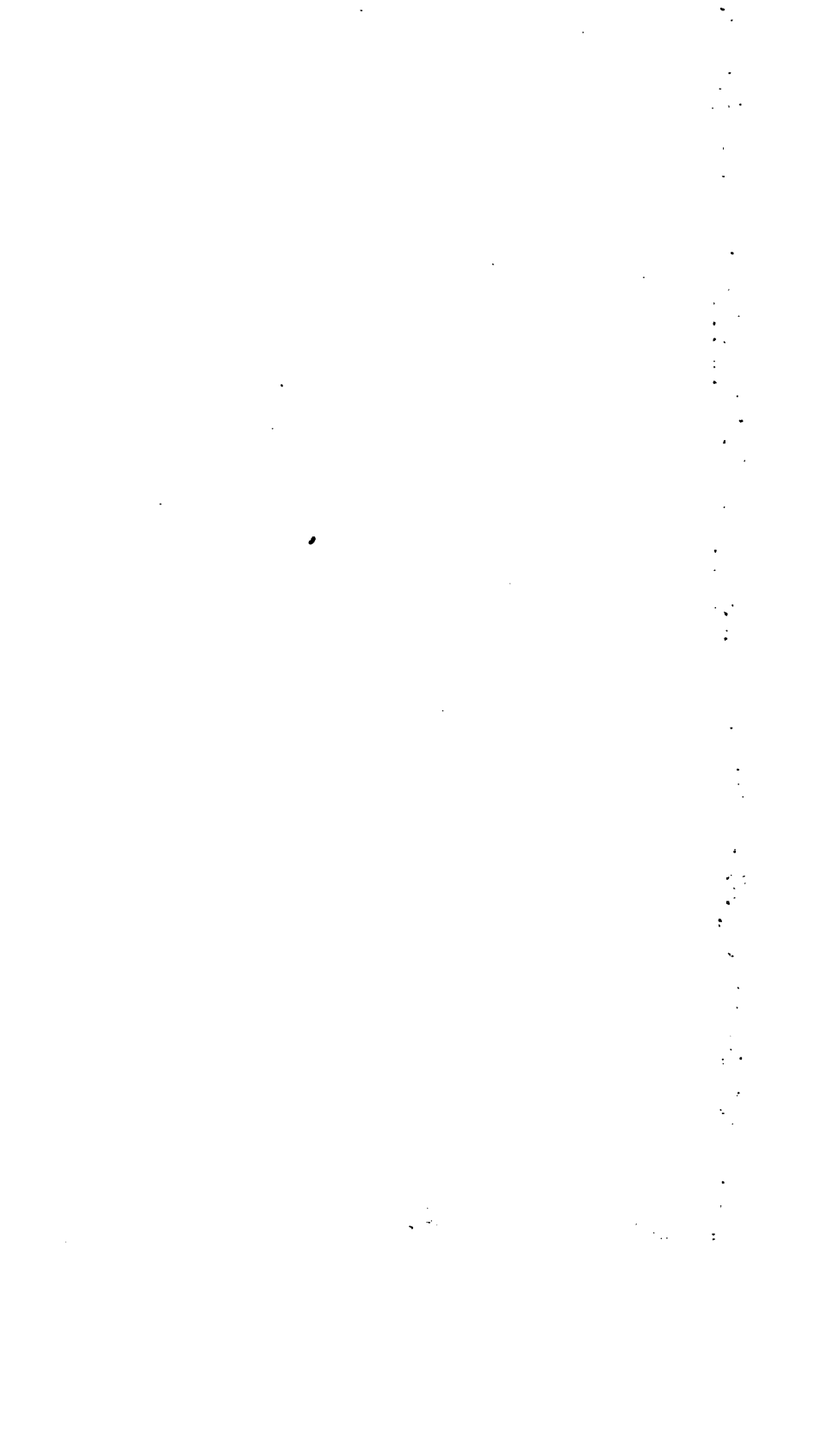
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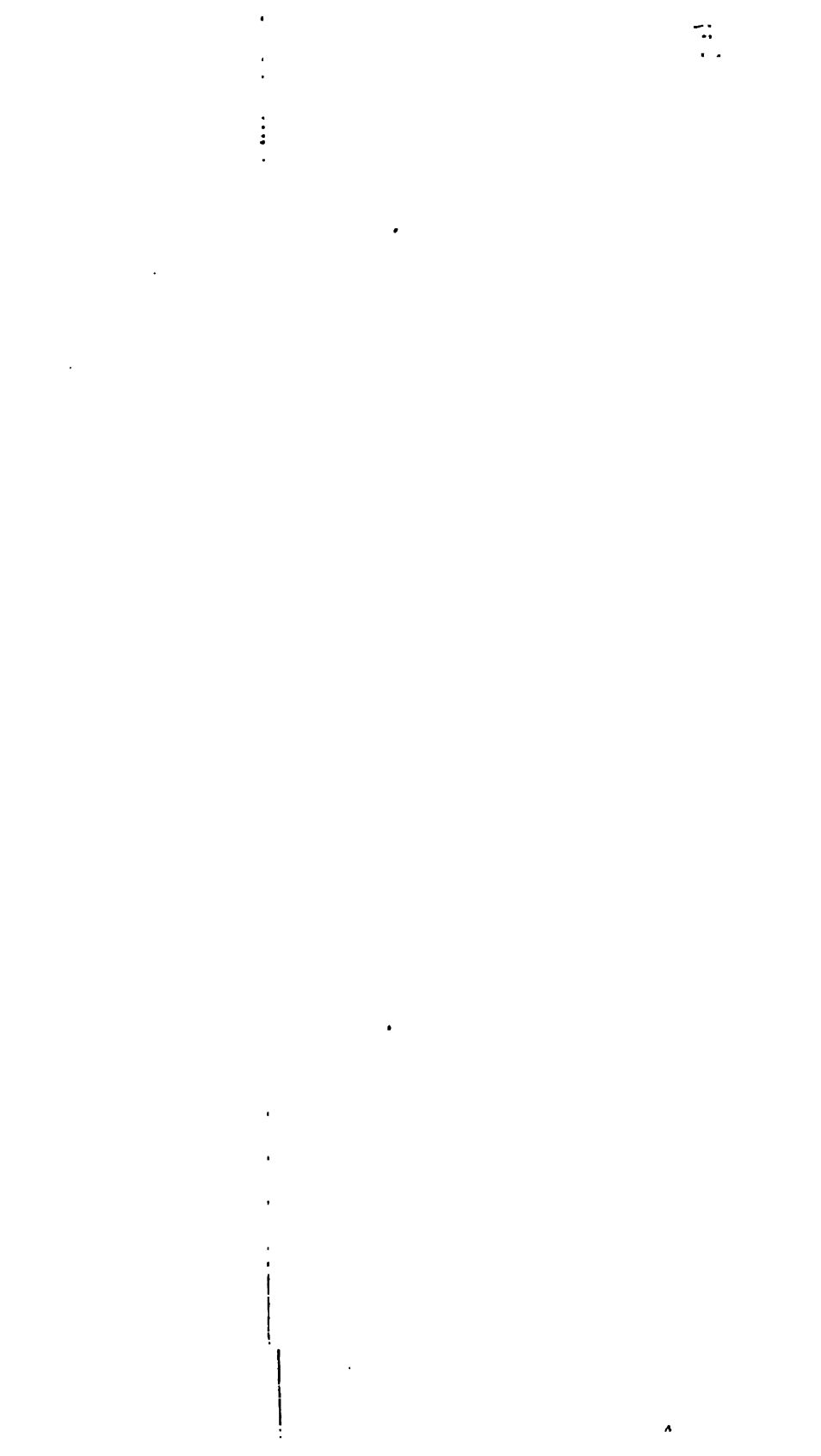
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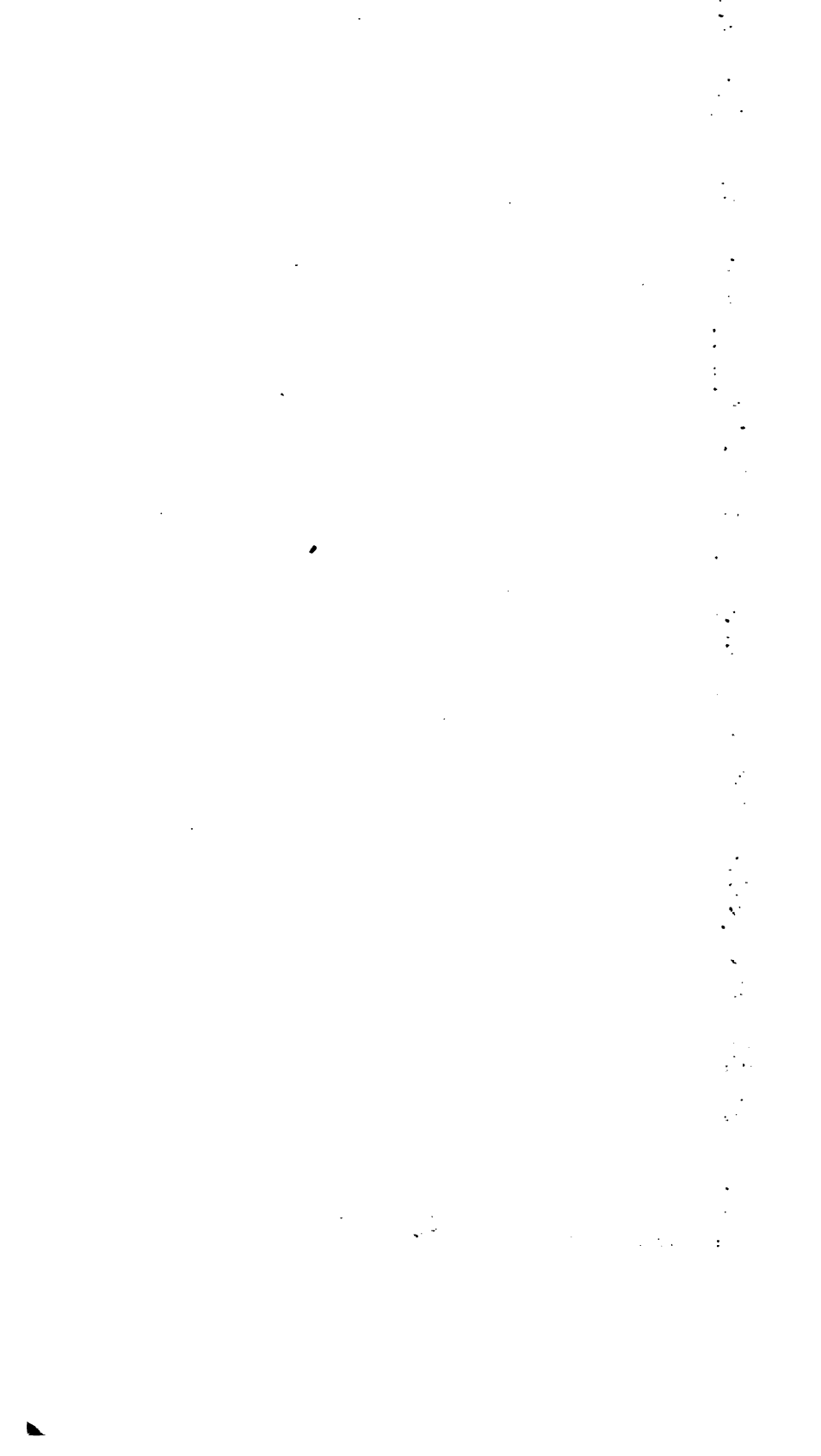
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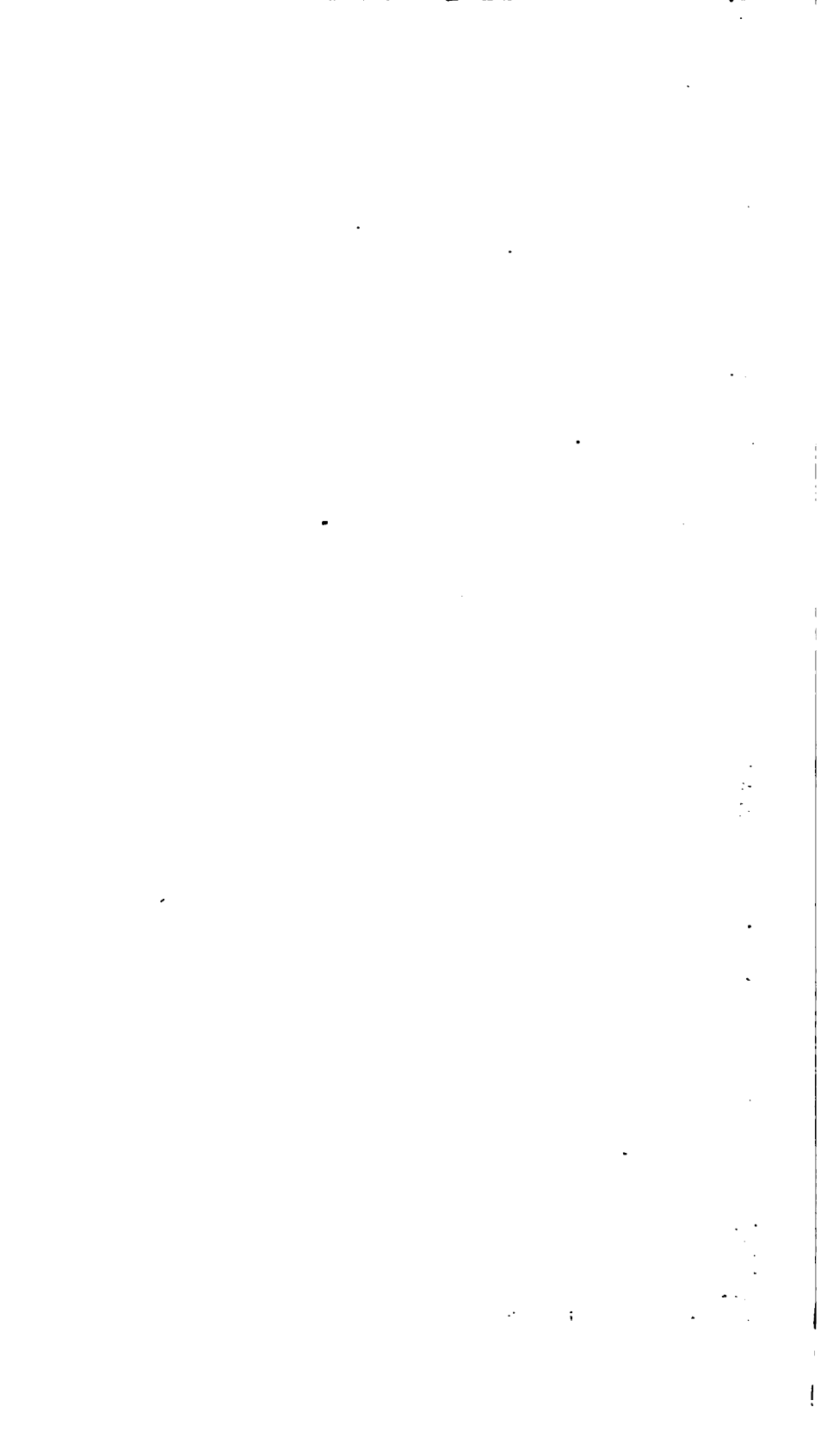
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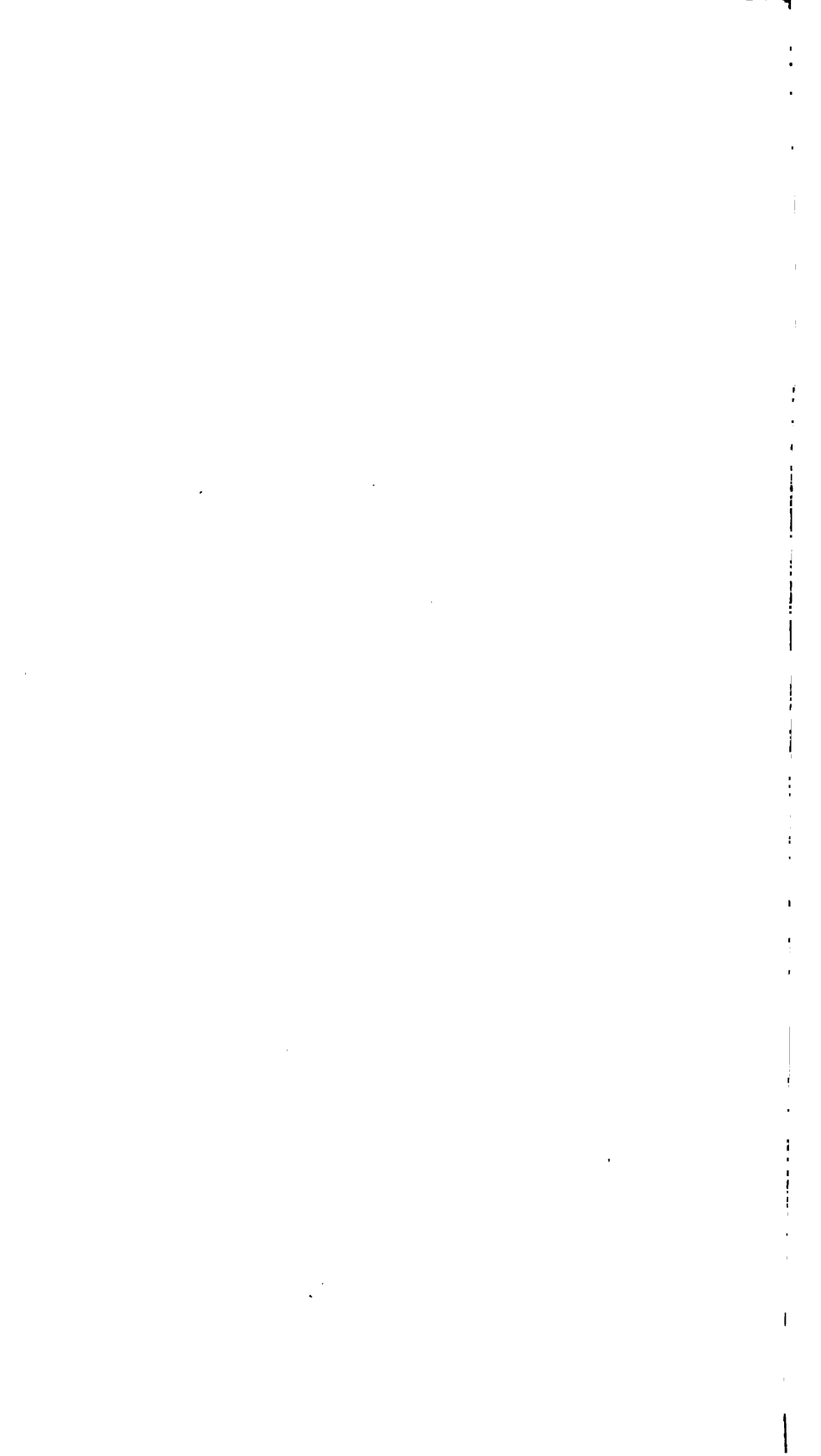
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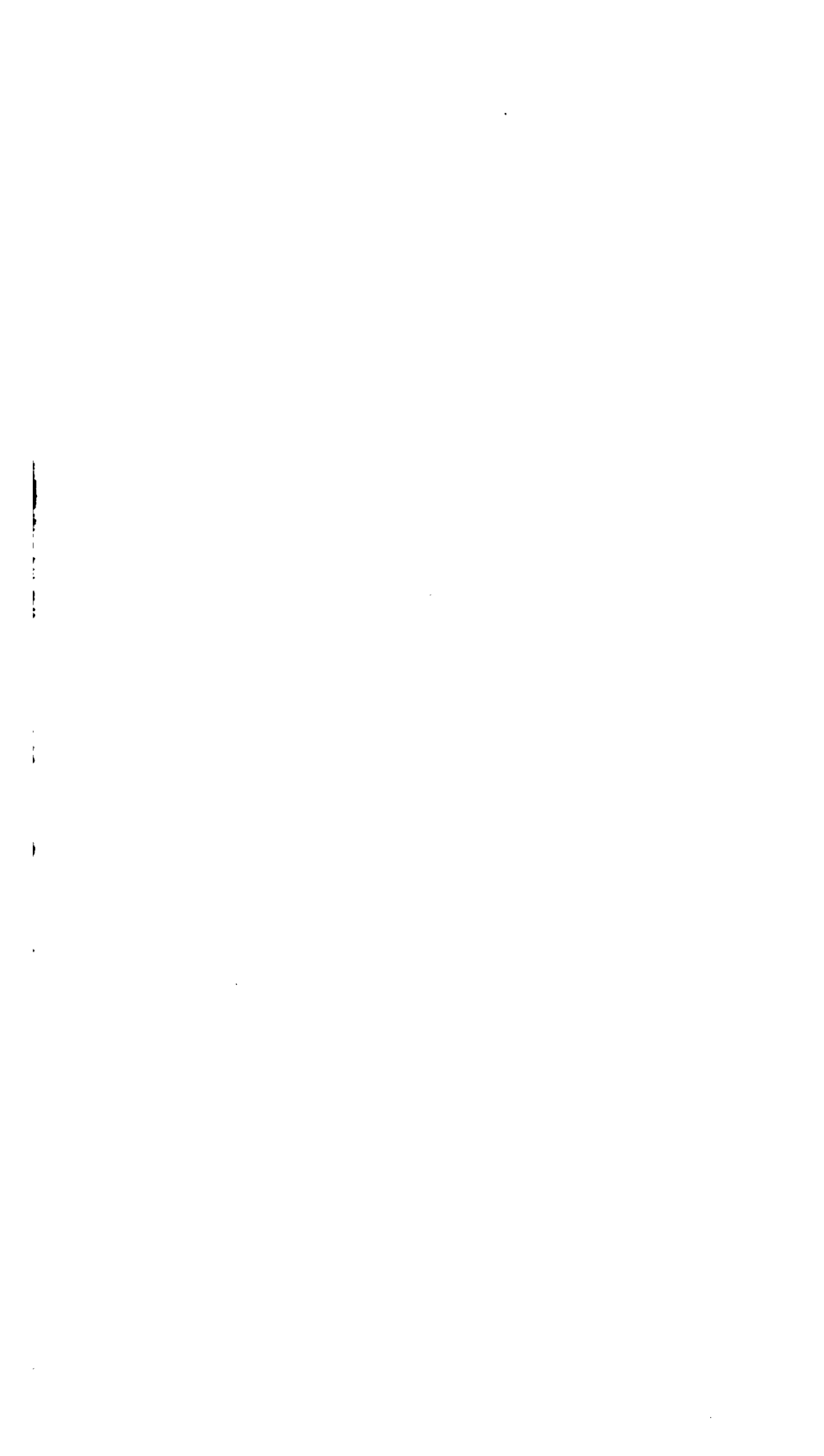
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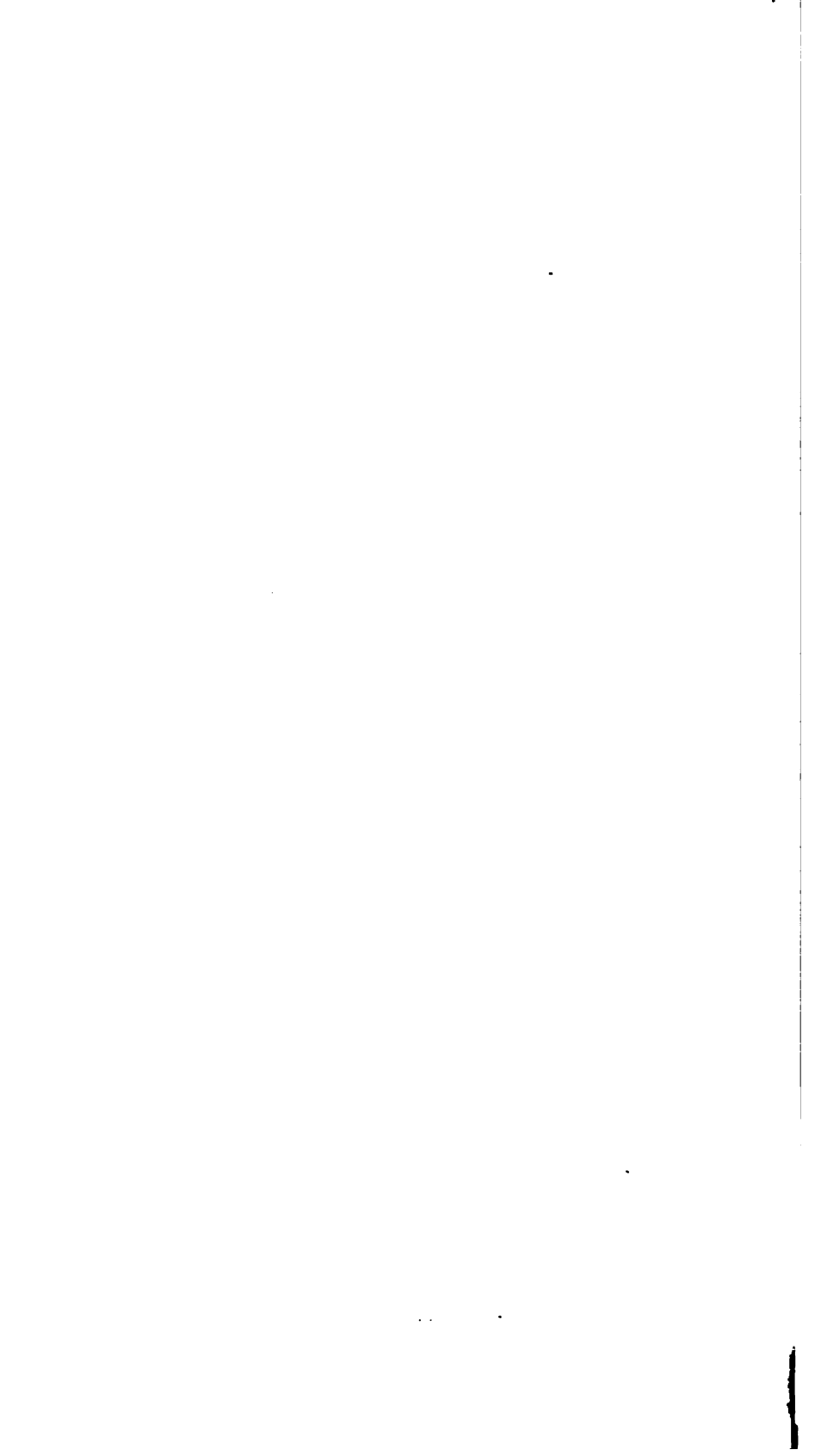
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